BELLCOMM. INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B63 09007

SUBJECT: Daytime Atmospheric X-ray Fluorescence and Its Effect on X-ray Astronomy - Case 630

DATE: September 5, 1969

FROM: F. F. Tomblin

ABSTRACT

Daytime atmospheric X-ray fluorescence will affect 20-35 Å X-ray astronomy only in low earth orbit when weak source visibility is desired. The effects of this fluorescence, caused by photoionization of atmospheric oxygen and nitrogen, can be considerably reduced by operating in orbits above 300 nm. At 225 nm, during solar quiet, the atmospheric fluorescence is approximately that of the lowest background X-ray flux measured in this wavelength region.

(NASA-CR-107209) DAYTIME ATMOSPHERIC X-RAY FLUORESCENCE AND ITS EFFECT ON X-RAY ASTRONOMY (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

I. INTRODUCTION

Solar radiation interacting with atmospheric constituents has become an important consideration with the advent of astronomical observatories in near-earth orbit. An example of this phenomenon is the Lyman alpha geocorona which extends to more than 10 earth radii. The Lyman alpha emission is present both day and night and has restricted the exposure time on certain UV cameras on the Smithsonian experiment end of OAO.

We consider here the K shell fluorescence at 23.6 Å and 31.6 Å of oxygen and nitrogen, respectively. These wavelengths are in a region of considerable interest in current X-ray surveys and their suppression is highly desirable. This fluorescence is generated by a two-step process. First, X-radiation with energy greater than the binding energy of the K electron (most tightly bound) is absorbed by the ion (photoabsorption). There is $\sim$80% probability that the K shell electron will be ejected instead of the less tightly bound electrons. The atom, now ionized, may decay by two modes: Auger electron emission or fluorescence. Fluorescence results when the L shell electron falls into the K shell. For ions with small Z (atomic number) the Auger effect is dominant and no fluorescence occurs. Decay into the K shell and fluorescence results in only approximately 1-2% of the excitations for oxygen and nitrogen.

This calculation requires knowledge of the shape of the solar X-ray spectrum only in the region just above the K shell binding energy (23.6 Å for oxygen), where the photoelectric absorption cross section is largest. Moreover, a reasonable model for the atmospheric composition and density above 100 nm is needed.

II. METHOD

Consider a volume element dV within the tenuous atmosphere above 100 nm. The solar X-ray flux passing through an element of surface normal to the flux is given by

$$\frac{dN(E)}{dE} \quad \frac{\text{photons}}{\text{cm}^2\text{sec keV}}$$

(see Figure 1). The attenuation of solar X-rays themselves may be neglected at these altitudes as it is much less than 1%.

The atmospheric density at the volume element is $\rho_i(h)$ where the index refers to the atomic species, and h is the altitude above the surface of the earth. The cross section per atom for the X-ray emission is given by $\sigma'(E)$, where E is the incident solar energy.

Thus the number of fluorescence photons N' generated within the volume dV at an altitude h is

$$d N_i' = dV \int_{E_K}^{\infty} dE \frac{dN\ (E)}{dE} \sigma_i'(E)\ \rho_i(h) \tag{1}$$

We assume the flourescence process is isotropic, so that the photon flux entering a surface distance r from dV, divide (1) by $4\Pi r^2$. Then the integration over all volume elements within the conical field of view of half angle α yields

$$N_i' = \frac{1}{2} \int_0^{\alpha} \int_0^{\infty} dr\ \sin\Omega d\Omega \rho_i(r,\Omega,\Theta) \int_{E_K}^{\infty} dE \frac{dN(E)}{dE} \rho_i(E) \tag{2}$$

The angle Ω is the local variable about Θ. Θ determines the look direction with respect to the local vertical. All calculations are performed with $\Theta=0$. For other angles ($\Theta<70°$) the simple multiplication by sec Θ will properly account for the increased density.

III. THE PHOTOELECTRIC CROSS SECTION

Close to the K shell edge the form for the photoelectric absorption cross section $\sigma(E)$ becomes complex because of the inapplicability of the Born approximation. An analytical form of the cross section has been determined[1] and is shown in Figure 2 for oxygen and nitrogen. If $\sigma'(E)$ is the cross section for X-ray fluorescence then

$$\sigma'(Z,E) = X(Z)\sigma(Z,E)$$

where X(Z) is the Auger Transition probability which is taken to be 2% for these calculations.[2]

IV. THE SOLAR X-RAY SPECTRUM

The solar X-ray spectrum is highly variable, depending on the state of solar activity. From the photoelectric cross section, it is important to notice that the wavelength region nearest the K shell edge is most susceptible to absorption. Thus, the important region for consideration here is from 10 to 23 Å for oxygen and from 10 to 31 Å for nitrogen.

The quiet corona emits both line and continuum radiation in this region. Enhancement may vary by a factor of 10 during large flares. Narrow-band absolute intensities are not yet available in this spectral region. However, spectra of quiet time corona has been taken[3] so that the relative intensities of line and continuum may be obtained. With an assumed coronal temperature one can compute the absolute intensities of the continuum processes.[4] The line emission contribution may then be added at each wavelength interval to obtain the total emission. This method may then be verified by comparing the result with the absolute broad band X-ray emission data taken during a period of similar solar activity.[5] The solar spectrum determined in this manner is shown in Figure 3 for $T_e = 2 \times 10^6$°K (solar quiet) and $T_e = 4 \times 10^6$°K (disturbed period). The flux is adjusted by a single scale factor to make the 8-20 Å flux computed in this manner correspond to the experimental data. Corrections are less than a factor of 2.

V. THE ATMOSPHERIC DENSITY

The atomic density in the F region is given by the scale height and exospheric temperature. This density may vary by a factor of 2 from day to night and by a factor of 10 from solar quiet to periods of extreme solar activity. Figure 4 shows the range of values to be anticipated.[6] Calculations will be performed with both extremes.

VI. RESULTS

The results of the calculation presented here are shown in Figure 5. They indicate that at low altitudes, significant contribution to the X-ray flux from extraterrestrial sources may be anticipated from atmospheric fluorescence by solar X-radiation. Results are shown in units of photons/cm^2 steradian. The X-ray radiation from L-K shell transitions should be 23.6 Å for oxygen and 31.6 Å for nitrogen; however, the bandwidth of detectors used will probably detect the sum of the radiation from both atoms (or ions). The oxygen contribution is considerably larger than the nitrogen contribution in all energies.

The Naval Research Laboratory has made extensive use of the 44-60 Å detector. Various portions of the sky have been searched for X-ray sources as well as the general X-ray background using this detector.[6] The intensities of the X-ray background listed in Figure 5 are from these experiments. While the atmospheric fluorescence is primarily at 20-35 Å, the galactic intensities at 44-60 Å will serve as a guide for order of magnitude estimates of the X-ray intensities anticipated.

VII. DISCUSSION

Figure 5 indicates the significant advantages of earth orbits above 300 nm for the performance of meaningful daytime X-ray astronomy experiments. An orbit of 300 nm is particularly important for measurements during high solar activity or when low level sources are being studied.

Since a majority of the known X-ray sources appear to be distributed near the center of the galaxy it is possible that for a short duration mission (two months) these sources would only be visible during the daytime portion of the orbit. Thus, for meaningful X-ray astronomy results at 20-35 Å, a 300 nm orbit is highly desirable, and during solar maximum it is essential.

F. F. Tomblin

1015-FFT-caw F. F. Tomblin

Attachments
References
Figures 1-5

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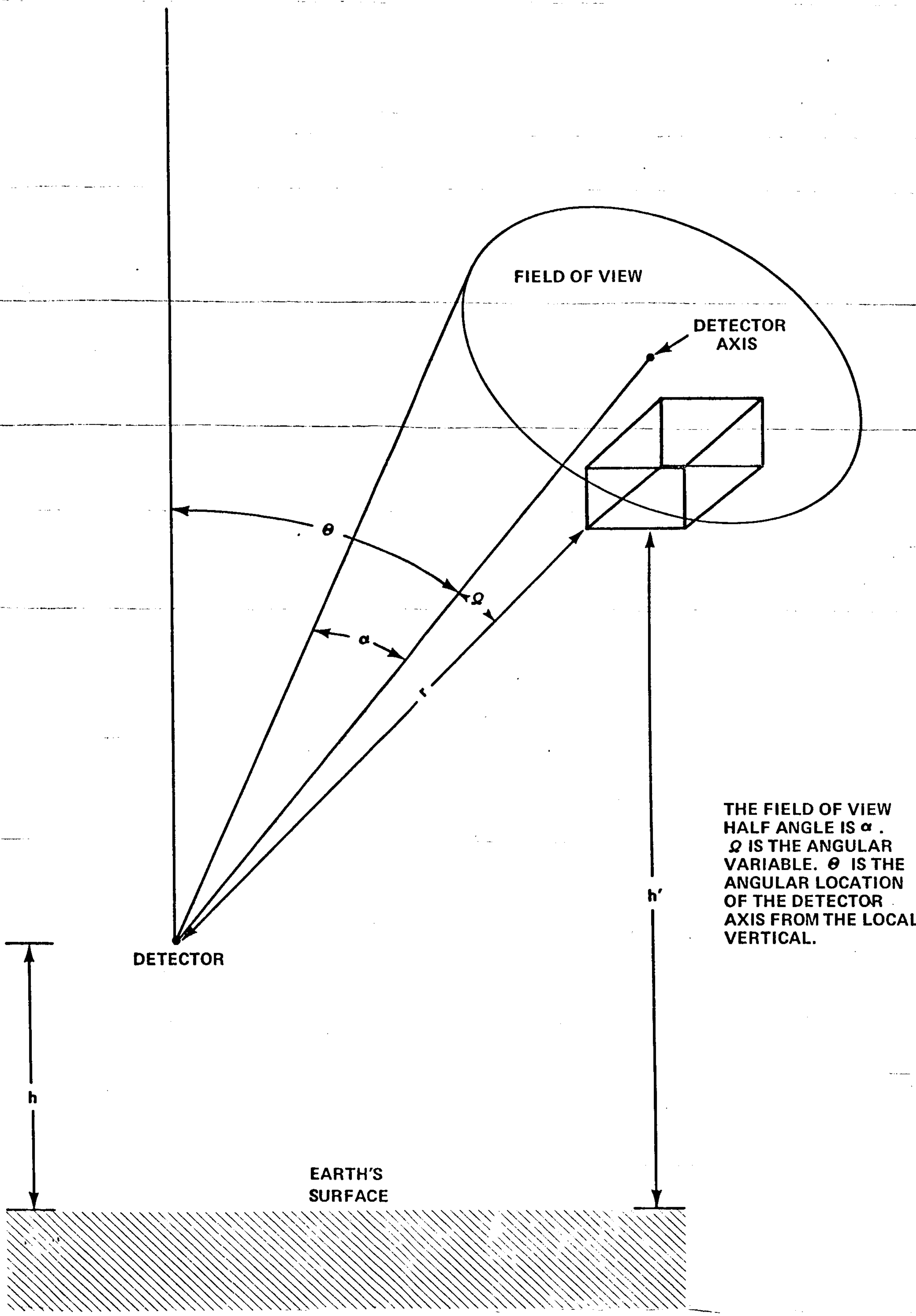

FIGURE 1 - DESCRIPTION OF COORDINATE SYSTEM

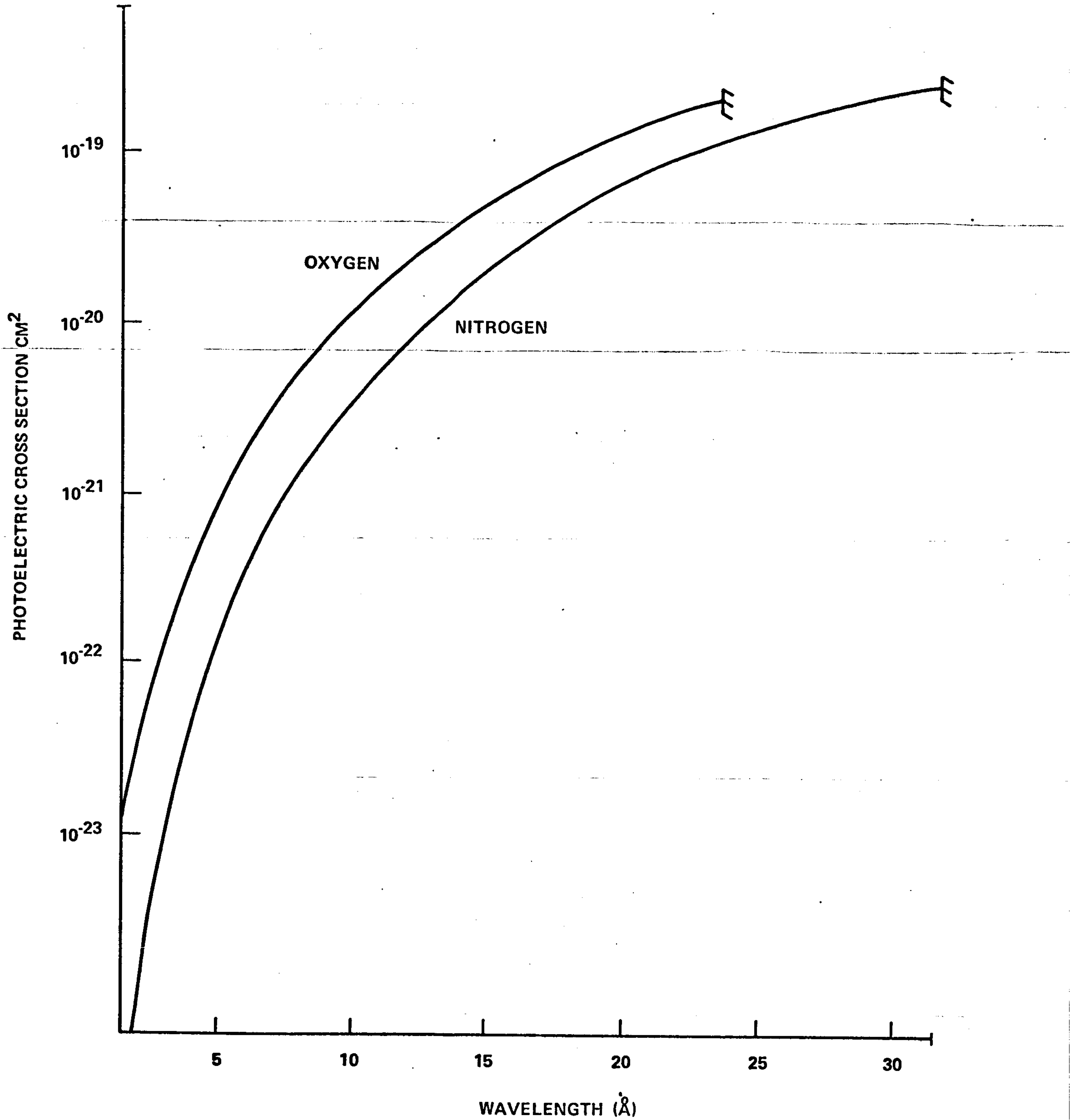

FIGURE 2 - PHOTOELECTRIC CROSS SECTION FOR OXYGEN AND NITROGEN NEAR THE K-SHELL EDGE

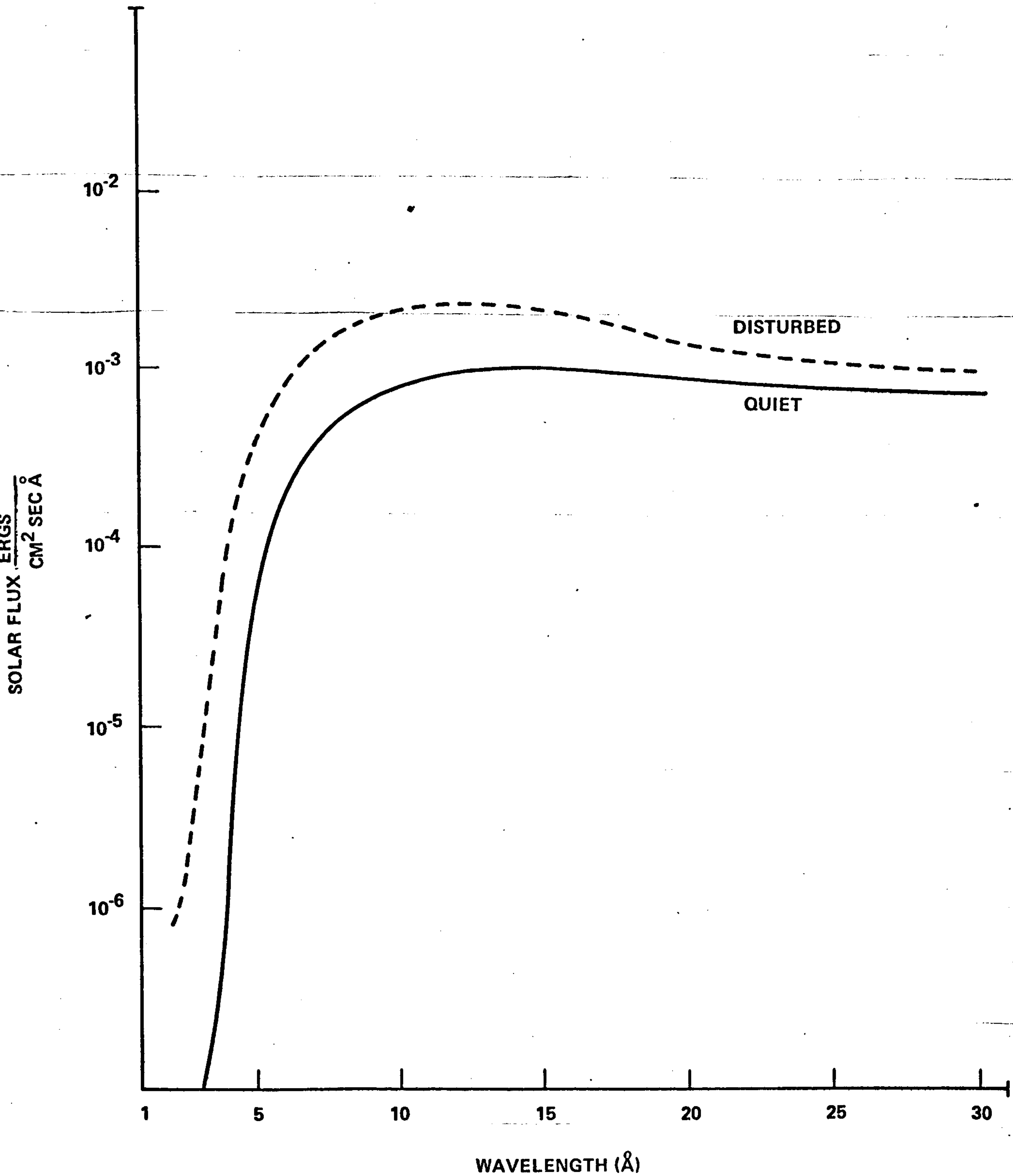

FIGURE 3 - SOLAR SPECTRUM FOR QUIET AND DISTURBED TIMES

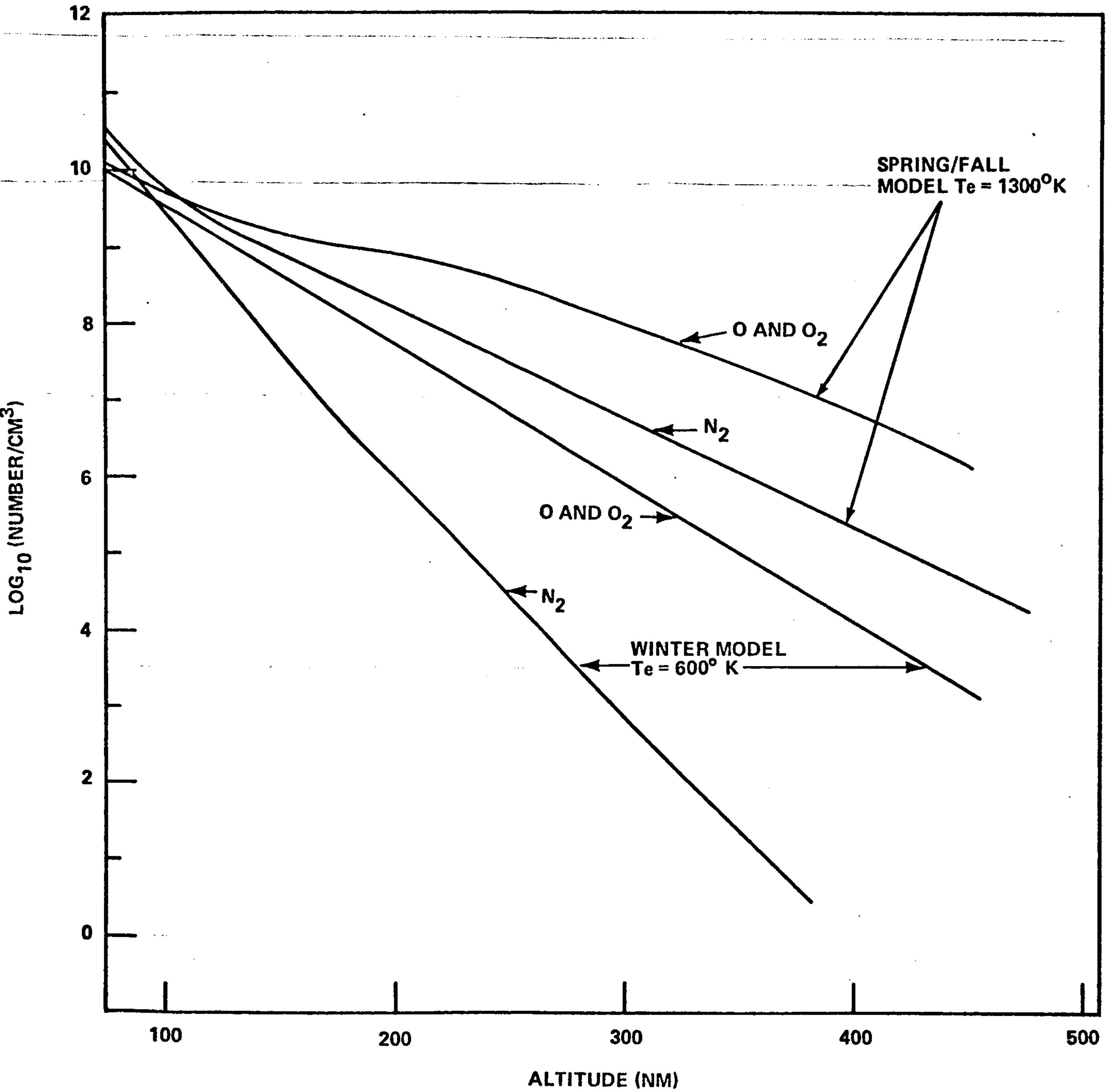

FIGURE 4 - DENSITIES OF VARIOUS ATMOSPHERIC CONSTITUENTS AS A FUNCTION OF ALTITUDE. (REF 6)

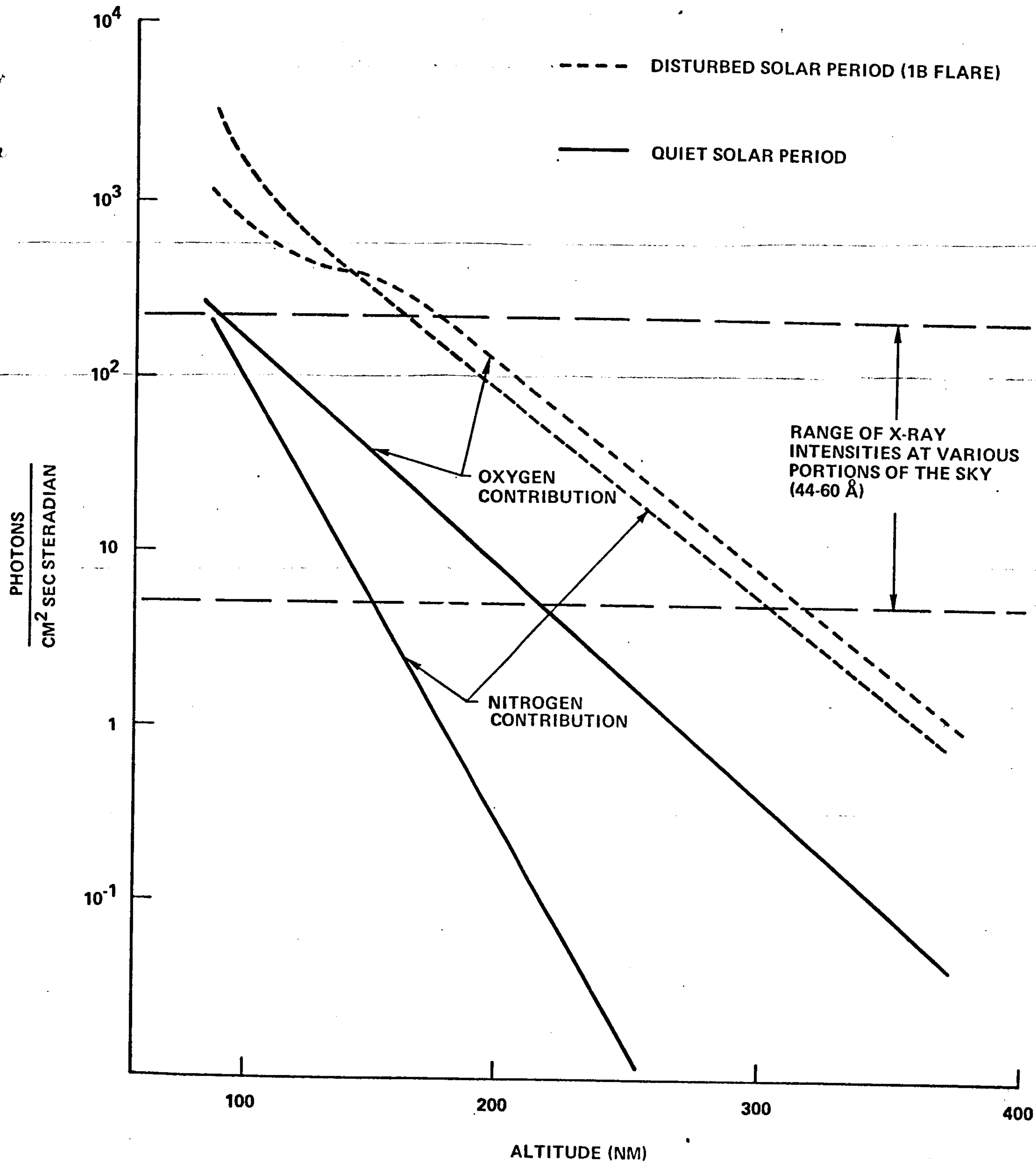

FIGURE 5 - FLUX/STERADIAN OF ATMOSPHERIC FLUORESCENCE AT VARIOUS ALTITUDES COMPARED WITH OBSERVED INTENSITIES OF THE DIFFUSE X-RAY FLUX MEASURED AT VARIOUS PORTIONS OF THE SKY